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AN AGE CONSTRAINT FOR THE VERY LOW-MASS STELLAR/BROWN DWARF BINARY 2MASS J03202839−0446358AB

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ABSTRACT

2MASS J03202839−0446358AB is a recently identified, late-type M dwarf/T dwarf spectroscopic binary system for which both the radial velocity orbit for the primary and spectral types for both components have been determined. By combining these measurements with predictions from four different sets of evolutionary models, we determine a minimum age of 2.0±0.3 Gyr for this system, corresponding to minimum primary and secondary masses of 0.080 $M_\odot$ and 0.053 $M_\odot$, respectively. We find broad agreement in the inferred age and mass constraints between the evolutionary models, including those that incorporate atmospheric condensate grain opacity; however, we are not able to independently assess their accuracy. The inferred minimum age agrees with the kinematics and absence of magnetic activity in this system, but not the rapid rotation of its primary, further evidence of a breakdown in angular momentum evolution trends amongst the lowest luminosity stars. Assuming a maximum age of 10 Gyr, we constrain the orbital inclination of this system to $i \gtrsim 53°$. More precise constraints on the orbital inclination and/or component masses of 2MASS 0320−0446AB, through either measurement of the secondary radial velocity orbit (optimally in the 1.2–1.3 μm band) or detection of an eclipse (only 0.3% probability based on geometric constraints), would yield a bounded age estimate for this system, and the opportunity to use it as an empirical test for brown dwarf evolutionary models at late ages.

Subject headings: stars: binaries: general — stars: fundamental parameters — stars: individual (2MASS J03202839−0446358) — stars: low mass, brown dwarfs

1. INTRODUCTION

Of the three most fundamental parameters of a star—mass, age and composition—age is arguably the most difficult to obtain an accurate measure. Direct measurements of mass (e.g., orbital motion, microlensing, asteroseismology) and atmospheric composition (e.g., spectral analysis) are possible for individual stars, but age determinations are generally limited to the coeval stellar systems for which stellar evolutionary effects can be exploited (e.g., pre-main sequence contraction, isochronal ages, post-main sequence turnoff). Individual stars can be approximately age-dated using empirical trends in magnetic activity, element depletion, rotation or kinematics that are calibrated against cluster populations and/or numerical simulations (e.g., Wilson & Wooley 1970; Skumanich 1972; Wielen 1977; Barnes 2007; Mamajek & Hillenbrand 2008; West et al. 2008). However, such trends are fundamentally statistical in nature, and source-to-source scatter can be comparable in magnitude to mean values. Age uncertainties are even more problematic for the lowest-mass stars ($M \lesssim 0.5\ M_\odot$), as post-main sequence evolution for these objects occurs at ages much greater than a Hubble time, and activity and rotation trends present in solar-type stars begin to break down (e.g., Mohanty & Basri 2003; Reiners & Basri 2008). For the vast majority of intermediate-aged (1–10 Gyr), very low-mass stars in the Galactic disk, barring a few special cases (e.g., low-mass companions to cooling white dwarfs; Silvestri et al. 2006) age determinations are difficult to obtain and highly uncertain.

Ages are of particular importance for even lower-mass brown dwarfs ($M \lesssim 0.075\ M_\odot$), objects which fail to sustain core hydrogen fusion and therefore cool and dim over time (Kumar 1962; Hayashi & Nakano 1963). The cooling rate of a brown dwarf is set by its age-dependent luminosity, while its initial reservoir of thermal energy is set by gravitational contraction and hence total mass. As such, there is an inherent degeneracy between the mass, age and observable properties of a given brown dwarf in the Galactic field population; one cannot distinguish between a young, low-mass brown dwarf and an old, massive one from spectral type, luminosity or effective temperature alone. This degeneracy can be resolved for individual sources through measurement of a secondary parameter such as surface gravity, which may then be compared to predictions from brown dwarf evolutionary models (e.g., Mohanty et al. 2004; Burgasser, Burrows & Kirkpatrick 2006; Leggett et al. 2007). However, surface gravity determinations are highly dependent on the accuracy of atmospheric models, which are known to have systematic problems at low temperatures due to incompleteness in molecular opacities (e.g., Freedman, Marley & Lodders 2008) and dynamic atmospheric processes (e.g., Cushing et al. 2008). Discrete metrics such as the presence of absence of Li I absorption (depleted in brown dwarfs more massive than 0.065 $M_\odot$ at

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ages $\gtrsim$200 Myr Rebolo, Martín, & Magazzu 1992; Bildsten et al. 1997), are generally more robust but do not provide a continuous measure of age for brown dwarfs in the Galactic field population.

Binary systems containing brown dwarf components can be used to break this mass/age degeneracy without resorting to atmospheric models. Specifically, systems for which masses can be determined via astrometric and/or spectroscopic orbit measurements, and component spectral types, effective temperatures and/or luminosities assessed, can be compared directly with evolutionary models to uniquely constrain the system age (e.g., Liu, Dupuy & Ireland 2008). Furthermore, by comparing the inferred ages and masses for each presumably coeval component, such systems can provide empirical tests of the evolutionary models themselves. A benchmark example is the young (∼300 Myr) binary—and perhaps triple—brown dwarf system Gliese 569B (Martín et al. 2000; Lane et al. 2001; Zapatero Osorio et al. 2004, 2005; Simon, Bender & Prato 2006). With both astrometric and spectroscopic orbit determinations, and resolved component spectroscopy, this system has been used to explicitly test evolutionary model tracks and lithium burning timescales (Zapatero Osorio et al. 2004, 2005) as well as derive component ages, which are found to agree qualitatively with kinematic arguments (e.g., Kenworthy et al. 2001). Other close binaries with astrometric or spectroscopic orbits have also been used for direct mass determinations (e.g., Bouy et al. 2004; Stassun et al. 2006; Joergens & Müller 2007; Ireland et al. 2008; Liu, Dupuy & Ireland 2008), but these systems generally lack resolved spectroscopy and therefore precise component characterization. They have also tended to be young, preventing stringent tests of the long-term evolution of cooling brown dwarfs. Older, nearby very low-mass binaries with resolved spectra (e.g., Burgasser & McElwain 2006; McElwain & Burgasser 2006; Martín et al. 2006; Stumpf et al. 2009) generally have prohibitively long orbital periods for mass determinations.

Recently, we identified a very low-mass binary system for which a spectroscopic orbit and component spectral types could be determined: the late-type source 2MASS J03202839−0446358 (hereafter 2MASS J0320−0446; Cruz et al. 2003; Wilson et al. 2003). Our independent discoveries of this system were made via two complementary techniques. Blake et al. (2008, hereafter Bl08) identified this source as a single-lined radial velocity variable, with a period of 0.67 yr and separation ∼0.4 AU, following roughly 3 years of high-resolution, near-infrared spectroscopic monitoring (see Blake et al. 2007). Burgasser et al. (2008, hereafter Bu08) demonstrated that the near-infrared spectrum of this source could be reproduced as an M8.5 plus T5±1 unresolved pair, based on the spectral template matching technique outlined in Burgasser (2007b). The methods used by these studies have yielded both mass and spectral type constraints for the components of 2MASS J0320−0446, and thus a rare opportunity to robustly constrain the age of a relatively old low-mass star and brown dwarf system in the Galactic disk.

In this article, we determine a lower limit for the age of 2MASS J0320−0446 by combining the radial velocity measurements of Bl08 and component spectral type determinations of Bu08 with current evolutionary models. Our method is described in § 2, which includes discussion of sources of empirical uncertainty and systematic variations from four sets of evolutionary models. We obtain lower limits on the age, component masses, and orbital inclination of the system, and compare our age constraint to expectations based on kinematics, magnetic activity and rotation of the primary component. In § 3 we discuss our results, focusing in particular on how future observations could provide bounded limits on the age and component masses of this system, and thereby facilitate tests of the evolutionary models themselves at late ages.

2. THE AGE OF 2MASS J0320−0446

2.1. *Component Luminosities*

Evolutionary models predict the luminosities and effective temperatures of cooling brown dwarfs over time, parameters that have been shown to correlate well with spectral type (e.g., Kirkpatrick et al. 2000; Golimowski et al. 2004; Nakajima, Tsuji & Yanagisawa 2004). Luminosity is the more reliable parameter, being based on the measured distance and broad-band spectral flux of a source, as opposed to model-dependent determinations of photospheric gas temperature and/or radius. However, in the case of 2MASS J0320−0446, neither distance nor component fluxes have been measured, the latter due to the fact that this system is as yet unresolved (and for the near future, unresolvable; see § 3). We therefore used the component spectral types of this system and luminosity measurements for similarly-classified, single (unresolved) sources from Dahn et al. (2002); Golimowski et al. (2004); Vrba et al. (2004) and Cushing, Rayner & Vacca (2005) to estimate the component luminosities.

For the M8.5 primary, there are 13 M8–M9 field dwarfs with bolometric luminosities (parallax distance and broad-band spectral flux measurements) reported in the studies listed above. Two of the sources—the M8 LHS 2397a, a known binary (Freed, Close, & Siegler 2003); and the M9 LP 944-20, believed to be a younger system (∼500 Myr, Tinney 1998)—are unusual sources and therefore excluded from this analysis. The mean bolometric magnitude of the remaining stars is $\langle M_{bol} \rangle$ = 13.36±0.29 mag, corresponding to $\log_{10} L_{bol}/L_{\odot}$ = -3.45±0.12.

For the T5±1 secondary, there are fewer field brown dwarfs with reliable luminosity measurements (1 T4.5 dwarf and 5 T6 dwarfs) and these show considerably greater scatter in their bolometric magnitudes: $\langle M_{bol} \rangle$ = 17.2±0.6. This scatter may be due in part to unresolved multiplicity, which appears to be enhanced amongst the earliest-type T dwarfs (Burgasser et al. 2006; Liu et al. 2006; Burgasser 2007a). Hence, we estimated the luminosity of 2MASS J0320−0446B using the M_{bol}/spectral type relation of Burgasser (2007a)[2]. A mean $\langle M_{bol} \rangle$ = 17.09±0.29 ($\log_{10} L_{bol}/L_{\odot}$ = -4.94±0.17) was adopted, where we have taken into account the uncertainty in the secondary spectral type and the M_{bol}/spectral type relation (0.22 mag). This value agrees well with esti-

[2] The coefficients of this polynomial relation reported in Burgasser (2007a) did not list sufficient significant digits, resulting in slight differences between the numerical relation and that shown in Figure 1 of the paper. The coefficients as defined should be $\{c_i\}$ = [1.37376e1, 1.90250e-1, 1.73083e-2, 7.40013e-3, -1.75144e-3, 1.14234e-4, -2.32248e-06], where $M_{bol} = \sum_{i=0}^{6} c_i \mathrm{SpT}^i$ and SpT(T0) = 10, SpT(T5) = 15, etc.

mates from Vrba et al. (2004, $\langle M_{bol}\rangle = 16.9\pm0.4$) and Golimowski et al. (2004, $\langle M_{bol}\rangle = 17.3\pm0.6$).

2.2. *Evolutionary Models*

In order to assess systematic uncertainties in the derived age and component properties, we considered four different sets of evolutionary models in our analysis: the cloudless models of Burrows et al. (1997, 2001, hereafter TUCSON models), the "COND" cloudless models of Baraffe et al. (2003, hereafter COND models), and the cloudless and cloudy models from Saumon & Marley (2008, hereafter SM08 models). All four sets of models assume solar metallicity, which is appropriate given that composite red optical and near-infrared spectra of 2MASS J0320−0446 show no indications of subsolar metallicity (Cruz et al. 2003, Bu08). The choice of "cloudless" evolutionary models (referring to the absence of condensate clouds in atmospheric opacities) is driven partly by their availability. In addition, the spectral energy distributions of the M8.5 and T5 components of 2MASS J0320−0446 are minimally affected by condensate cloud opacity (e.g., Allard et al. 2001). However, cloud opacity in the intermediate L dwarf stage may slow radiative cooling during this phase and bias the inferred age of the T-type secondary (SM08), although Chabrier et al. (2000) have claimed that clouds have only a "small effect" on evolution. To test this possibility, we chose to examine both the cloudless and cloudy SM08 models, the latter of which takes into account photospheric cloud opacity in thermal evolution through the use of atmospheric models generated according to the prescriptions outlined in Ackerman & Marley (2001) and SM08.

Figure 1 compares the luminosity estimates for the two components of 2MASS J0320−0446 to the evolutionary tracks of each model set. The luminosities (and their uncertainties) constrain the mass/age parameter space of each component, as illustrated in Figure 2. Component masses generally increase with system age, as more massive low mass stars and brown dwarfs take longer to radiate their greater reservoir of heat energy from initial contraction. The mass of the primary of this system reaches an asymptotic value of $\sim$0.08–0.09 $M_\odot$ for ages $\gtrsim$1 Gyr, consistent with a hydrogen-fusing very low-mass star. If the system is younger than $\sim$400 Myr, the primary could be substellar. Note that ages $\lesssim$300 Myr (primary masses $<$0.065 $M_\odot$) can be ruled out based on the absence of Li I absorption at 6708 Å in the unresolved red optical spectrum of this source (Cruz et al. 2003). The mass of the secondary increases across the full age range shown in Figure 2 as this component is substellar up to 10 Gyr. There is some divergence in the evolutionary tracks at late ages for this component, however; the TUCSON models predict a mass near the hydrogen-burning limit, while the SM08 cloudless and cloudy models predict masses above and below the Li-burning minimum mass, respectively. The kink in the mass/age relation of 2MASS J0320−0446B at ages of 200-300 Myr, particularly in the COND and SM08 models, reflects the prolonged burning of deuterium in brown dwarfs with masses just above 0.013 $M_\odot$, producing higher luminosities at this temporary stage of evolution. The mass ratio of the system, $q \equiv M_2/M_1$, also increases as a function of age, ranging from $\sim$0.2 at 100 Myr to a maximum of $\sim$0.8 at 10 Gyr.

2.3. *Constraints from the Primary Radial Velocity Orbit*

With constraints in the mass/age phase space provided by the component luminosities and evolutionary models, we can now use the radial velocity orbit to break the mass/age degeneracy. The radial velocity variations measured by Bl08 only probe the recoil velocity of the primary of the 2MASS J0320−0446 system. These observations provide a coupled constraint between the masses and inclination of the system:

$$M_2 \sin i = (0.2062\pm0.0034)(M_1 + M_2)^{2/3} \quad M_\odot, \qquad (1)$$

(Bl08) where i is the inclination angle of the orbit, and M_1 and M_2 are the masses of the primary and secondary components in solar mass units, respectively. We can make a geometric constraint that $\sin i \leq 1$, which yields a transcendental equation for the lower limit of the secondary component mass of the system as a function of the primary component mass. Using our age-dependent lower bound for the latter based on the evolutionary models (including luminosity uncertainties) the constraint on $M_2 \sin i$ from Eqn. 1 translates into a minimum secondary mass as a function of age, as shown in Figure 2. Finally, the age at which the upper bound of the secondary component mass (based on the evolutionary models) crosses the radial velocity minimum mass line corresponds to the minimum age of the system.

All four models predict a minimum age for 2MASS J0320−0446 in the range 1.7–2.2 Gyr (Table 1). This age is in qualitative and quantitative agreement with those inferred by Bl08 from the kinematics of the 2MASS J0320−0446 system[3] and stellar age/activity trends. In the case of the latter, the optical spectrum of 2MASS J0320−0446 shows no detectable Hα emission (Cruz et al. 2003), even though >90% of nearby M8–M9 dwarfs exhibit such emission (Gizis et al. 2000; Schmidt et al. 2007; West et al. 2008). For comparison, West et al. (2008) estimate an "activity lifetime" (i.e., timescale for Hα emission to drop below detectable levels) of $8^{+0.5}_{-1.0}$ Gyr for M7 dwarfs. This age may be too high of an estimate for 2MASS J0320−0446, as the increase in activity lifetimes for spectral types M2–M7 observed by West et al. (2008) may not continue for later spectral types. Magnetic field lines are increasingly decoupled from lower-temperature photospheres, and the frequency and strength of Hα emission decrease rapidly beyond type M7/M8 (e.g., Gizis et al. 2000; Gelino et al. 2002; Mohanty et al. 2002; West et al. 2004). Hence, the absence of magnetic emission from 2MASS J0320−0446A is merely indicative of an older age, as is its kinematics.

Rotation is a third commonly-used empirical age diagnostic for stars, based on the secular angular momentum loss observed amongst solar-type stars through the emission magnetized stellar winds (e.g., Skumanich 1972; Soderblom, Duncan, & Johnson 1991). However, so-called gyrochronological relations calibrated for these stars are not necessarily applicable to lower-mass

[3] Combining the systemic radial velocity from Bl08 with the revised proper motion and distance estimates from Bu08, the *UVW* space motions of this system are U = -38±5 km s^{-1}, V = -20±3 km s^{-1} and W = -32±4 km s^{-1}, where we assume an LSR solar motion of $U_\odot$ = 10 km s^{-1}, $V_\odot$ = 5.25 km s^{-1} and $W_\odot$ = 7.17 km s^{-1} (Dehnen & Binney 1998). Wielen (1977), equation 8, predicts an age >1.6 Gyr at the 95% confidence level for these kinematics.

objects, due both to the fully convective interiors of the latter and the decoupling of field lines from low-temperature atmospheres (e.g., Reiners & Basri 2008). Indeed, 2MASS J0320−0446A proves to be a relatively rapid rotator, with an equatorial spin velocity of $V_{eq} \sin i$ = 16.5±0.5 km s^{-1} and a rotation period < 7.4 hr (Bl08). For solar-type stars, this rapid rotation generally indicates a young age; an extrapolation (in color) of gyrochronology relations by Barnes (2007, equation 3, assuming $B - V \approx 2.1$ for 2MASS J0320−0446A; e.g., Leggett 1992) yields an age of only ∼0.1 Myr. This is inconsistent with the absence of Li I absorption, space kinematics and lack of magnetic emission from this source. Clearly, rotation does not provide a useful age metric for the 2MASS J0320−0446 system, further emphasizing the breakdown of age/angular momentum trends in the lowest-mass stars.

The derived minimum age and radial velocity constraints of the 2MASS J0320−0446 system allow us to constrain model-dependent minimum masses for its components as well; $M_1 \geq$ 0.080–0.082 $M_\odot$ and $M_2 \geq$ 0.053–0.054 $M_\odot$. The ranges in these values reflect variations between the four evolutionary models (Table 1). Note that there is essentially no difference in the minimum masses inferred from the cloudy and cloudless SM08 models. The minimum mass ratio of the system, $q >$ 0.60–0.62, is also consistent across the evolutionary models, and in accord with the general preference of large mass ratio systems observed amongst very low-mass binaries (>90% of known binaries with $M_1 < 0.1$ $M_\odot$ have $q > 0.6$; see Burgasser et al. 2007).

Finally, while the minimum ages and masses of 2MASS J0320−0446 are inferred assuming $\sin i \leq 1$, it is possible to constrain the maximum masses and minimum orbital inclination of this system assuming an upper age limit. Adopting $\tau < 10$ Gyr, we infer $\sin i >$ 0.80–0.86, corresponding to $i >$ 53°–59°. This constraint is only slightly more restrictive than the $i > 44°$ lower limit determined by Bl08 assuming that the fainter secondary must have a lower mass than the primary. It does not significantly improve the chances that this system is an eclipsing edge-on system (∼0.3% by geometry). Maximum primary (0.088 $M_\odot$) and secondary masses (0.066–0.075 $M_\odot$) are effectively set by the luminosity constraints and evolutionary models. Here we see the most significant difference between the models, a 13% discrepancy in the maximum mass of the secondary component, likely due to different treatments of light element fusion near the Li- and H-burning minimum masses. This variation confirms the importance of older binary systems as tests of long-term brown dwarf evolution, particularly near fusion mass limits. We also note that there is little difference (∼4%) in the maximum masses inferred from the SM08 cloudy and cloudless models, illustrating again the negligible role of cloud opacity in the long-term evolution of brown dwarfs like 2MASS J0320−0446B.

3. DISCUSSION

The combination of component luminosities, radial velocity orbit of the primary and evolutionary models have allowed us to estimate the minimum age of the 2MASS J0320−0446 system and its component masses. The ages are consistent between four evolutionary models of brown dwarfs, and are more precise (although not necessarily more accurate) than estimates based on as-yet poorly-constrained statistical trends in kinematics, magnetic activity and angular momentum evolution. However, a bounded age estimate remains elusive due to the unknown inclination of the system and determination of component masses. As discussed in Bl08, the inclination of the 2MASS J0320−0446 orbit is irrelevant if the radial velocity orbit of the secondary can be determined. In that case, one need only compare the derived system mass ratio and component luminosities to evolutionary models to obtain a bounded age estimate. Measurement of the secondary motion in the K-band data of Bl08 was not possible due to the very large flux contrast between the components; Bl08 rule out a contrast ratio of $\lesssim$10:1 at these wavelengths; spectral template fits from Bu08 predict a contrast ratio of $\gtrsim$350:1. A more effective approach would be the acquisition of radial velocity measurements in the 1.2-1.3 μm band where the T dwarf secondary is considerably brighter and the contrast ratio is closer to 20:1 (depending on the absolute magnitude scale; see discussion in Bu08). At these contrasts, the radial velocity of the secondary can be measured using existing techniques for high-contrast spectroscopic binary systems (e.g., Zucker & Mazeh 1994).

Alternately, if this system is observed to eclipse, then $\sin i \approx 1$ and the age of the system is uniquely determined. Table 1 lists the ages corresponding to this scenario, ranging from $2.5^{+1.0}_{-0.7}$ Gyr to $3.2^{+1.3}_{-0.9}$ Gyr for the four models examined (uncertainties include the full range of possible primary and secondary masses for which Eqn. 1 and the luminosity constraints are satisfied). The relatively small age uncertainties estimated in this scenario (25–60%) are dominated by uncertainties in the component luminosities, which could be measured from primary and secondary eclipse depths over a broad range of optical and infrared wavelengths (e.g., Stassun et al. 2006). Such measurements are currently more feasible than resolved imaging measurements, as the tight separation inferred from the radial velocity orbit, $a \sin i = a_1 \frac{1+q}{q} \sin i \approx 0.4$ AU (Bl08, assuming $q \approx 0.6$), implies a projected separation of $\lesssim$17 mas, below the diffraction limit of the Keck 10m telescope at near-infrared wavelengths. Yet the scientifically valuable measurements possible in an eclipsing scenario must be tempered by this scenario's low probability. For a maximum age of 10 Gyr, we can only constrain the inclination of the 2MASS J0320−0446 system to $i \gtrsim 53°$, and hence an eclipse probability of ∼0.3%.

Regardless of whether 2MASS J0320−0446 is an eclipsing pair, determination of its orbit inclination and/or component masses is a necessary step for testing brown dwarf evolutionary models at late ages, specifically through agreement of system parameters with model isochrones (c.f.., Zapatero Osorio et al. 2004). The power of such a test is the long lever arm of time provided by older field binaries such as 2MASS J0320−0446, resulting in large differences in luminosities and effective temperatures for the more common near equal-mass systems (e.g., Allen 2007). There may in fact be many such systems to exploit in this manner. Simulations by Bu08 of brown dwarf pairs in the vicinity of the Sun predict that 12-25% of all M8–L5 dwarf binaries have component spectral types that can be inferred from unresolved, near-

infrared spectroscopy using the method outlined in Burgasser (2007b). Perhaps as many as 50% of these systems may be short-period radial velocity variables (Maxted & Jeffries 2005; Basri & Reiners 2006). Identification and follow-up of these systems would complement the evolutionary model tests currently provided by younger systems (Zapatero Osorio et al. 2004; Stassun et al. 2006; Liu, Dupuy & Ireland 2008; Dupuy, Liu & Ireland 2009) and would more robustly address uncertainties associated with low-temperature light-element fusion, interior thermal transport, and substellar interior structure as their effects are compounded over time.

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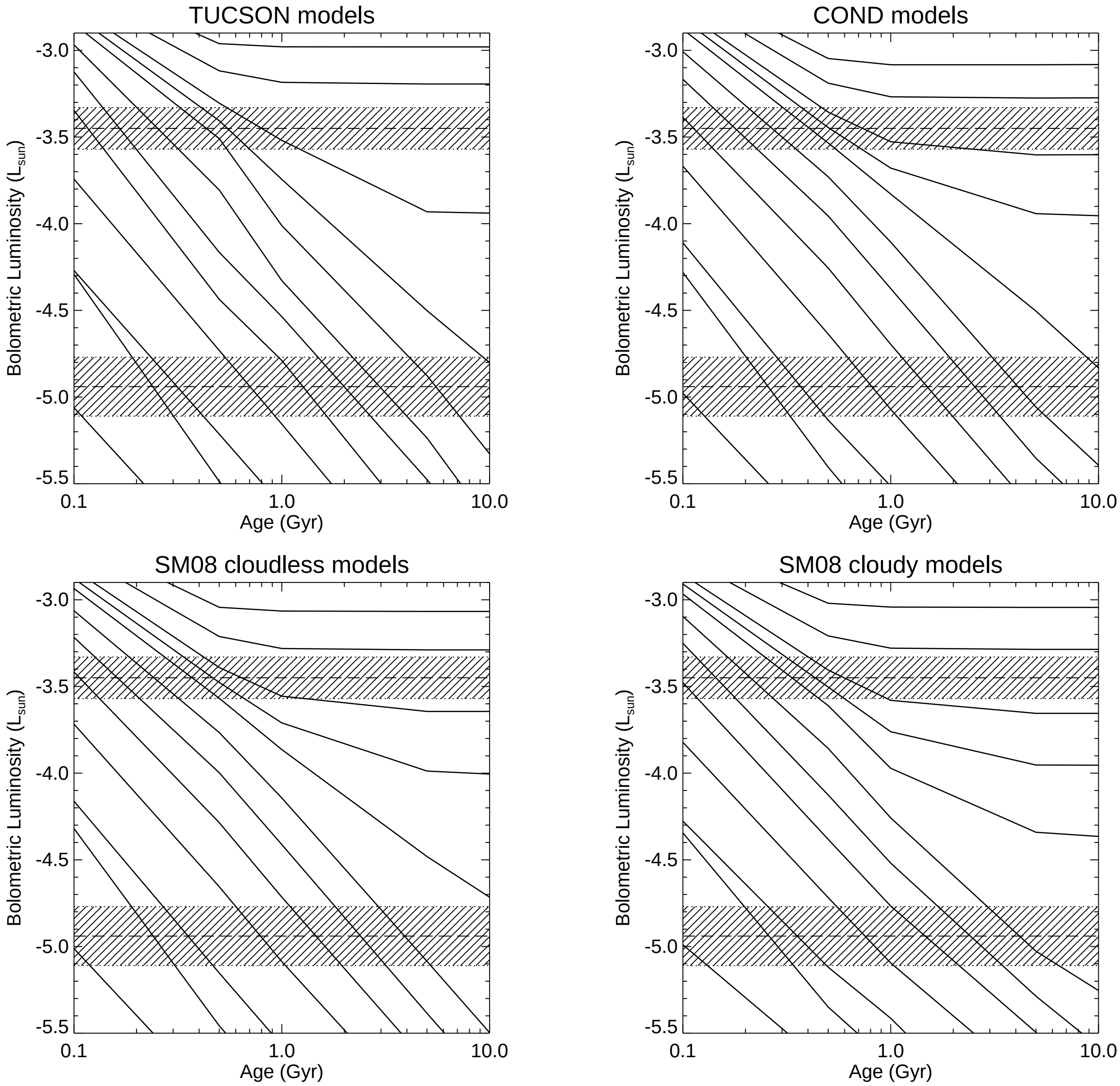

FIG. 1.— Luminosity evolutionary tracks based on models from Burrows et al. (1997, 2001, upper left); Baraffe et al. (2003, upper right); and Saumon & Marley (2008, bottom left: cloudless; bottom right: cloudy). Tracks are shown for masses of 0.01, 0.015, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.075, 0.08, 0.09, and 0.1 $M_{\odot}$, from lower left to upper right in each panel. The estimated luminosities and uncertainties of the two components of 2MASS J0320−0446 are indicated by the hatched regions.

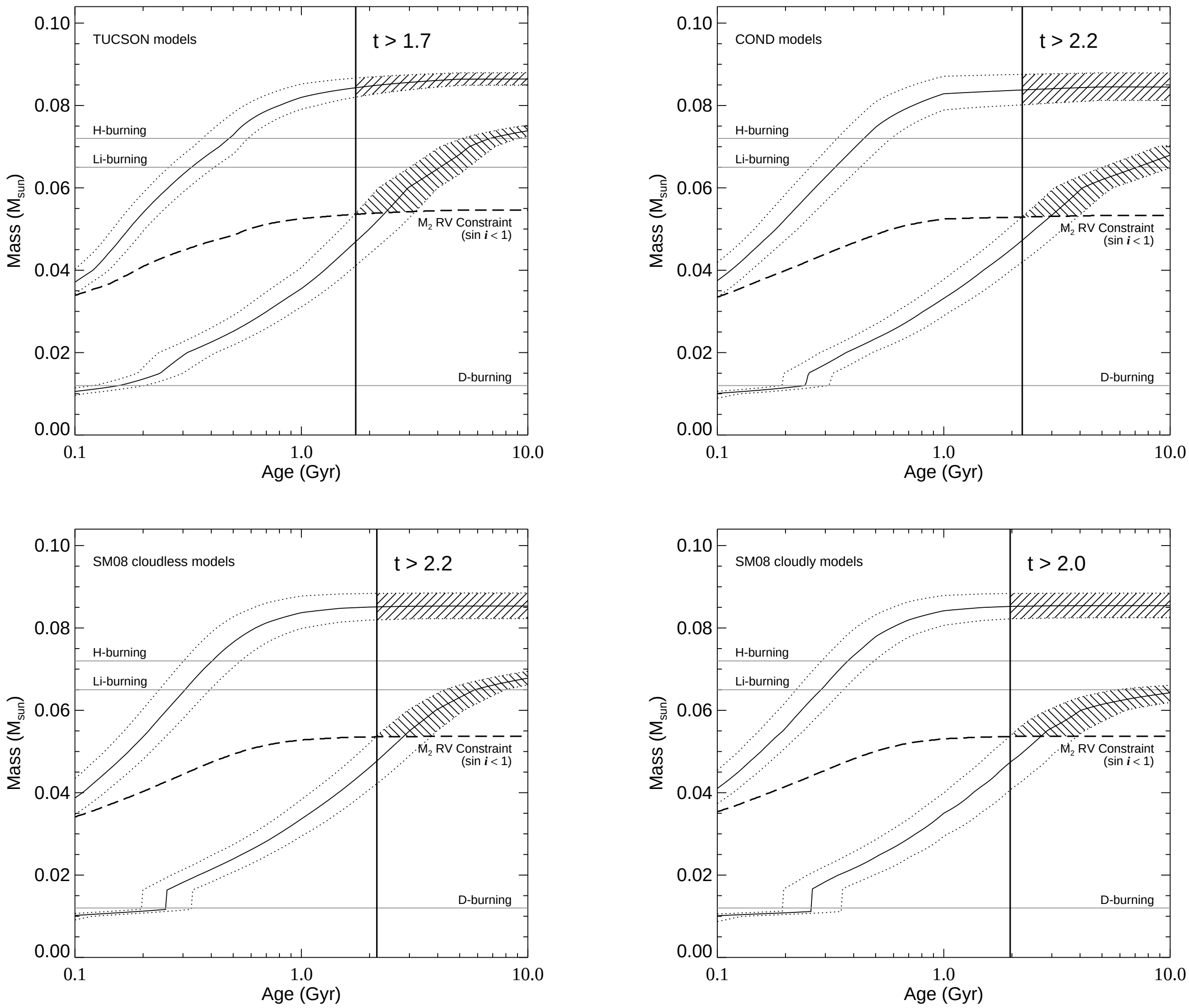

FIG. 2.— 2MASS J0320−0446 component masses (solid lines; dotted lines indicate uncertainty range) as a function of age based on the component luminosity constraints shown in Figure 1. Age-dependent constraints on the minimum secondary mass based on the primary radial velocity orbit and lower bound of the primary mass, and assuming $\sin i \leq 1$, are indicated by dashed lines. The intersection of this line with secondary component mass constraints (based on luminosity) sets the minimum age of the 2MASS J0320−0446 system, 1.7–2.2 Gyr. The hatched regions indicate parameter spaces allowed by the luminosity and radial velocity measurements and evolutionary models. Horizontal grey lines indicate threshold masses for core hydrogen (0.075 $M_\odot$), lithium (0.065 $M_\odot$) and deuterium fusion (0.013 $M_\odot$), assuming solar metallicity.

TABLE 1
Mass and Age Constraints for the 2MASS J03202839−0446358 System.

Parameter	TUCSON cloudless	COND cloudless	SM08 cloudless	SM08 cloudy
Minimum age (Gyr)	1.7	2.2	2.2	2.0
Minimum $\sin i$[a]	0.80 (53°)	0.82 (55°)	0.83 (56°)	0.86 (59°)
M_1 ($M_\odot$)[a]	0.082–0.088	0.080–0.088	0.082–0.088	0.082–0.088
M_2 ($M_\odot$)[a]	0.054–0.075	0.053–0.070	0.054–0.069	0.054–0.066
M_2/M_1	0.62–0.89	0.60–0.87	0.61–0.84	0.61–0.80
Age for $\sin i = 1$ (Gyr)	$2.5^{+1.0}_{-0.7}$	$3.2^{+1.3}_{-0.9}$	$3.0^{+1.2}_{-0.8}$	$2.8^{+1.7}_{-0.9}$

[a]Minimum $\sin i$ and maximum masses and mass ratios assume that the age of 2MASS J0320−0446 is less than 10 Gyr.